Climate Services 1 (2016) 39–52

Contents lists available at ScienceDirect

Climate Services

journal homepage: www.elsevier.com/locate/cliser

Consistent economic cross-sectoral climate change impact scenario analysis: Method and application to Austria

Karl W. Steininger [a,b,*], Birgit Bednar-Friedl [a,b], Herbert Formayer [c], Martin König [d]

[a] *Wegener Center for Climate and Global Change, University of Graz, Graz, Austria*
[b] *Department of Economics, University of Graz, Graz, Austria*
[c] *Institute of Meteorology, University of Natural Resources and Life Sciences, Vienna, Austria*
[d] *Environmental Impact Assessment and Climate Change, Environment Agency Austria, Vienna, Austria*

A R T I C L E I N F O

Article history:
Available online 22 February 2016

Keywords:
climate impact
local impact
economic evaluation
adaptation

A B S T R A C T

Climate change triggers manifold impacts at the national to local level, which in turn have various economy-wide implications (e.g. on welfare, employment, or tax revenues). In its response, society needs to prioritize which of these impacts to address and what share of resources to spend on each respective adaptation. A prerequisite to achieving that end is an economic impact analysis that is consistent across sectors and acknowledges intersectoral and economy-wide feedback effects. Traditional Integrated Assessment Models (IAMs) are usually operating at a level too aggregated for this end, while bottom-up impact models most often are not fully comprehensive, focusing on only a subset of climate sensitive sectors and/or a subset of climate change impact chains. Thus, we develop here an approach which applies climate and socio-economic scenario analysis, harmonized economic costing, and sector explicit bandwidth analysis in a coupled framework of eleven (bio)physical impact assessment models and a uniform multi-sectoral computable general equilibrium model. In applying this approach to the alpine country of Austria, we find that macroeconomic feedbacks can magnify sectoral climate damages up to fourfold, or that by mid-century costs of climate change clearly outweigh benefits, with net costs rising two- to fourfold above current damage cost levels. The resulting specific impact information – differentiated by climate and economic drivers – can support sector-specific adaptation as well as adaptive capacity building.

Practical implications

The rise in greenhouse gas emissions has triggered manmade climate change, with past emissions already strongly determining its dimension up to mid-century and current and future emissions (respectively global emissions reductions) determining the severity of climate change beyond (IPCC, 2013). Climate change induces manifold impacts around the globe. Adaptation to climate change at the regional to local level is thus a crucial policy area to keep net ecological, economic and social damages within limits (IPCC, 2014). One core ingredient to frame adequate adaptation and respective policy is detailed knowledge on the impacts foreseen, across all fields, including system feedback, and in a consistent way. This information can then be used for relative comparison and prioritization of adaptation options both among impact fields and relative to other policy areas.

Sophisticated global and regional circulation models supply rich regional climate scenarios under future climate change (see e.g. for Europe Jacob et al., 2014). Impact studies build upon these scenarios to quantify the specific impacts within their very field and region, from agriculture to energy, tourism, or water supply, to name a few. Any such scenario analysis of future impacts requires the choice of not only a specific climate scenario but also of a socio-economic, land use and demographic scenario, making it difficult to compare results of any two of such studies, as these assumptions will usually differ. While quantifying climate impacts bottom-up is crucial, when it is done in such a scattered way, it is difficult to obtain consistent information for a cross-sectoral comparison.

The approach we present here closes this gap by first ensuring consistency across impact fields; i.e. covering all impact fields identified for a country, requiring their analysis to apply a common climate and socioeconomic scenario and – to identify ranges

* Corresponding author.
E-mail address: karl.steininger@uni-graz.at (K.W. Steininger).

http://dx.doi.org/10.1016/j.cliser.2016.02.003

– respective consistent climate and socioeconomic scenario ensembles. Second, the approach also acknowledges the fact that any specific impact within one field (or economic sector) usually will trickle on to other sectors in the economy, causing impacts there as well, and also triggering macroeconomic feedback effects. An increase in heat waves, for example, triggers labour productivity loss in the manufacturing of machinery, which will raise the cost of intermediate inputs for many other sectors, affecting their output, price levels, and tax revenues in turn.

The analysis starts in each impact field by identifying all economically relevant impact chains potentially triggered by climate change, as well as a selection and application of models or appropriate estimates available to quantify the respective (bio)physical impacts such as harvest losses due to an increase in droughts (Fig. 1). As a second step, each physical impact is translated into an economic impact by means of a consistent costing approach. We distinguish five types of economic impacts: changes in productivity, in production cost, in investment requirement, in final demand or in public expenditures. Where market data are available, market evaluation approaches are applied; for health impacts and impacts on urban green, indirect approaches can be applied such as via Life Years Lost or preventive costs for expansion of parks to reduce heat island effects.

As a third step, the economy-wide and cross-sectoral effects are assessed within a multi-sectoral computable general equilibrium (CGE) model, with the inputs being the economic impacts originating in each field. This macroeconomic impact model analysis informs pertinent stakeholders about the economy-wide implications their impact fields trigger and might indicate a higher relevance of adaptation; it also informs stakeholders at the economy-wide scale, such as national ministries, about aggregate implications on e.g. tax revenues or unemployment rates, so they are able to react proactively. In comparison, Integrated Assessment Models (IAMs) are usually less suitable for both of these ends, as such models are both characterized by much less economic sector (interaction) detail and are based on much more aggregated impact functions.

To get informed on the spread of potential impacts, we identify as a fourth step which climatic and socioeconomic parameter constellations contribute to significantly higher (respectively lower) net damages, separately for each impact field. For a consistent evaluation, the starting point is the aggregate impact evaluation for one common mid-range climate and a reference socio-economic scenario across all impact fields. The bandwidth of results can be explored by appropriate combination of scenarios that enhance (or diminish) damages in specific sectors. For example, longer summer heat waves and increasing agricultural harvest losses can be consistent with higher winter temperatures that could raise winter tourism losses but will simultaneously induce higher benefits due to additional heating cost savings. Such impact field specific bandwidth analysis of impact ranges is crucial for well-designed explicit adaptation (e.g. height of dams to protect against riverine flooding), but also guides how socioeconomic development has to be steered to reduce vulnerability (e.g. social policy increasing equality will enhance adaptive capacity of the most vulnerable to respond to heat waves).

Finally, the communication strategy translates modelling results into fact sheets and narratives which inform stakeholders in a non-scientific language on the impacts for each impact field as well as in total, and point to limitations in coverage and modelling assumptions. For the application of this approach to Austria, these fact sheets are available in both German and English at http://coin.ccca.at.

Fig. 1 depicts the flow of analysis, integrating sectoral (bio)physical and economic impact assessments, the macroeconomic model, and range-of-impact analysis. Finally, a deliberate communication strategy of results acknowledges specific stakeholder information needs.

To see the type of results from such an approach, we provide exemplary results for climate change impacts in Austria by 2050 under the assumption that no additional public adaptation or mitigation measures are taken than those already agreed upon today ('inaction assumption'). Impact fields analysed are the fourteen identified for Austria by the Austrian Strategy for Adaptation to Climate Change (Federal Ministry of Agriculture, Forestry, Environment and Water Management, 2013): Agriculture, Forestry, Water Supply and Sanitation, Tourism, Energy, Construction and Housing, Human Health, Ecosystem Services/Biodiversity, Transportation and Mobility, Manufacturing and Trade, Cities as well as Spatial Planning (these two in our analysis considered as one field Cities and Urban Green), Protection from Natural Hazards, and Disaster Risk Management (with the last two here considered also as one field labeled Catastrophe Management).

We find significant cross-sectoral amplification of damages due to sectoral supply chain linkages: e.g. heat-induced productivity losses in manufacturing translate to damages across the whole economy at the three- to fourfold scale, or losses in overnight stays in winter tourism translate to 60% higher overall economic damages (as the former reduces intermediate supplies to the accommodation sector, e.g. of food). Economic gains due to climate change, such as reduced heating demand and higher crop yields in agriculture, turn out to be small relative to losses. Weather and climate-related economic damages are found to at least quadruple in a mid-range climate scenario by 2050 relative to today. Acknowledging different possible scenarios relevant to the impact fields indicates a range of damages from a quarter less to doubling these mid-range monetary damage values. However, for example, more than a third of these damages could be avoided by no further development in any flood-prone zones.

Such a consistent framework allows informed conclusions on adaptation in both spheres: explicit adaptation action but also the reduction of vulnerability, e.g. by steering socioeconomic development in such a way that construction in flood-prone zones is prohibited or poverty of the elderly is reduced which increases their heat adaptation capacity. The results, however, also point out the specific benefit of (global) greenhouse gas mitigation for the national and local scale.

Resource demands to carry out such an analysis – but also the feasibility of which impact fields can be included within a reasonable time frame – crucially depend on the availability of climate impact models and availability of base data sets in sufficient temporal and spatial resolution. Moreover, such a study necessitates inter- and transdisciplinary collaboration of (regional) climate scientists to supply an ensemble of (localized) climate scenarios, economists to advise impact field teams on consistent impact costing and transferring these impacts to the macroeconomic model, and a broad array of respective field scientists for each impact field analysed (from agronomists to different engineering disciplines).

Whether (bio)physical impact models are available or need to be set up has also important implications for resource demands. For the application to Austria, we evaluated only those impact chains where impact models had been available or for which impacts could be meaningfully transferred from other cases in the international literature based on the climate parameters. In our case, resources were used for running existing impact models for the new common climate and socioeconomic scenarios and respective climate dependent indicators, for translating physical impacts into economic ones in a consistent way, for setting up a macroeconomic model for the overall assessment and for devising the uncertainty (i.e. range-of-impacts) analysis and communication strategy. These tasks were accomplished by the collaboration of 18 research teams, involving a total of 42 researchers. The project was accomplished within 18 months, with results available in a book publication (Steininger et al., 2015a), one overall and ten impact field fact sheets, and a narrative document. The scale of total resource demand was close to half a million Euros for the breadth of impact fields analysed.

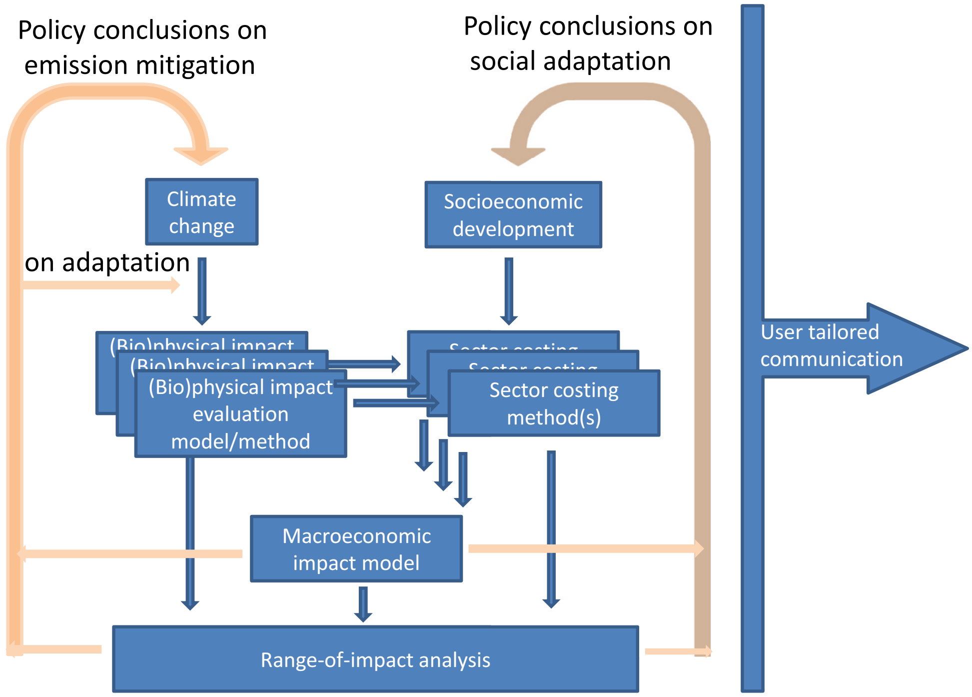

Fig. 1. Consistent economic cross-sectoral climate impact analysis: integration of assessments and models.

Introduction

The rise in greenhouse gas emissions has triggered manmade climate change, with past emissions already strongly determining its dimension up to mid-century and current and future emissions (respectively global emissions reductions) determining the severity of climate change beyond (IPCC, 2013). Climate change induces manifold impacts around the globe. Adaptation to climate change at the regional to local level is thus a crucial policy area to keep net ecological, economic and social damages within limits (IPCC, 2014).

Many countries around the world have started to develop national adaptation strategies and plans. For instance, by the end of 2015, 21 European states had adopted national adaptation plans (European Commission and European Environmental Agency, 2015). When implementing these adaptation strategies and plans, one key question is how limited (financial) resources can be used most effectively both for adaptation vis-à-vis other policy areas but also among different impact fields (climate sensitive sectors). However, most adaptation strategies do not even address the financing of adaptation options or their prioritization (Biesbroek et al., 2010).

A prerequisite for such an adaptation policy appraisal is the assessment of the economic consequences of climate change impacts, arising in different impact fields, in a consistent way (European Environmental Agency, 2007). The economic consequences of climate change without any (planned) adaptation, also called the cost of inaction, could then be compared to the gross costs of adaptation (i.e. costs of adaptation and of eventual climate impact damages remaining), leading to a ranking of policy options both within adaptation policy and across policy areas.

In this article, we illustrate how such an economic assessment of the costs of climate change impacts can be conducted at the national scale by integrating regional climate scenarios, (bio)physical impact models, a consistent sectoral costing methodology, a macroeconomic model, a range-of-impact analysis, and a user-tailored communication strategy. Moreover, we provide illustrative results for the case of Austria and discuss how these can inform practical decision making.

While there is a growing body of literature assessing the economic impacts of climate change at the global, regional, and national level, most studies remain incomprehensive by either focusing on only a subset of climate sensitive sectors such as agriculture, energy, and sea level rise, or by focusing on a subset of relevant impact chains (e.g. just considering supply side effects but ignoring demand side effects) (Agrawala et al., 2011). In general, two strands of literature can be distinguished in this field: top-down assessments in the tradition of integrated assessment models (IAMs) and bottom-up assessments, most commonly in the computable general equilibrium (CGE) tradition. The three most often applied IAMs to date are DICE (Dynamic Integrated Climate and Economy), PAGE (Policy Analysis of the Greenhouse Effect), and FUND (Climate Framework for Uncertainty, Distribution, and Negotiation), with model descriptions given by Nordhaus (1991, 2011); Hope (2006) – on which the Stern review is based (Stern, 2007) – and Tol (2002a, 2002b), respectively. They are used to provide total net present values for future damage over time and to estimate the marginal social costs of carbon (the damage cost of an extra ton of GHG emissions). Such models are usually based on a very aggregated "damage function", most often translating temperature change to GDP loss at the aggregate level only. Their use also to this end has been questioned (for a detailed discussion see e.g. Pindyck, 2013).

In comparison, bottom-up impact assessments using CGE models have been used in several European scale projects and studies on OECD countries which assess jointly-occurring climate change impacts for several climate sensitive sectors (Aaheim et al., 2012, Ciscar et al., 2011, 2012; OECD, 2015) as well as several further studies with a single sector focus (e.g. Bigano et al., 2008, Bosello et al., 2007, 2012). The main advantage of this modelling class is that it provides larger sectoral detail and is hence better suited to depict the different impact chains and their cross-sectoral and macroeconomic feedback effects (OECD, 2015).

One drawback to existing bottom-up impact assessment studies is that they focus on a selection of key climate sensitive sectors, such as agriculture, energy, and sea level rise, and a selection of climate parameters (most often only temperature and sea level rise) and thereby inherently remain incomprehensive. Moreover, any such scenario analysis of future impacts requires the choice of not only a specific climate scenario but also of a socio-economic, land use and demographic scenario, making it difficult to compare and impossible to combine results of any two of such studies, as these assumptions will usually differ between studies. While quantifying climate impacts bottom-up is crucial, when it is done in such a scattered way, it is difficult to obtain consistent information for a cross-sectoral comparison.

In this article, we close this gap (i) by looking jointly into all impact fields for a single country, regardless of whether they are a priori regarded as most vulnerable or not, (ii) by using consistent climate and socioeconomic scenario assumptions within sector-specific (bio)physical impact models, and (iii) by evaluating these impacts with a consistent economic costing methodology which is then fed into a national-scale computable general equilibrium (CGE) model and an uncertainty (i.e. range-of-impacts) assessment (Fig. 1). We complement this economy-wide analysis with a communication strategy (see also http://coin.ccca.at and Steininger et al., 2015c), which translates results acknowledging stakeholder needs by also providing current impact numbers (to address the adaptation deficit), as well as alternative estimation approaches for areas which cannot yet be assessed in the macroeconomic framework.

Materials and methods

The consistent integration of various sector analyses into the common economic framework suggested here builds upon several model components (see also Fig. 1). First, consistency across sectors can obviously be achieved by the definition of a common scenario, here referring to both climate (see the section *The climate scenarios and climate-dependent indicators derived*) and socioeconomic development (see the section *The socioeconomic scenarios*). Second, consistent translation of sectoral (physical) impacts into economic values (see the section *Sectoral impact modelling: the direct costs of climate change impacts*) and interlinkages (see the section *Macroeconomic impact modelling*) marks the soft-link integration of sectoral models to a national level multisector economic model. While such an analysis relating to a single, but common scenario enables one to derive one common aggregate figure on economic impacts of climate change, consistent across different sectors, for the analysis of uncertainties, a closer look is necessary on ranges of impacts differentiated by sector (see the section *Range-of-impact analysis*). Finally, a communication strategy to address specific user needs enhances usability of results in shaping adaptation and foresight planning (see the section *Communication strategy*).

The climate scenarios and climate-dependent indicators derived

The method reported here has been applied to Austria (Steininger et al., 2015a), which will be used to serve as an example to illustrate its application. Experts of each impact field identified climate dependent indicators most relevant in driving impacts in their respective fields (e.g. frost days in April defined as days in April when daily minimum temperature is below –4.0 °C).

To assess the range of potential future climate change in Austria (climate change signal denoting the difference between the reference period 1981 to 2010 and 30-year climate periods centering at 2030 and 2050), the monthly data for temperature and precipitation of 17 Global Circulation Models (GCMs) and 14 Regional Circulation Models (RCMs), each forced by one of three different emissions scenarios (RCP 4.5, 6.0 and 8.5), were used. GCM, and even standard RCM results, are far too coarse to resolve the complex topography of the Alps within Austria, which is relevant for actual impacts and needs to be reflected in indicators. Therefore, the calculation of the relevant climate indicators required further localized scenario data (1×1 km). This was carried out for one of the climate change scenarios: a very high resolution (10 km) RCM simulation of the RCM CCLM (Meissner et al., 2009) forced with the ECHAM5 A1B, as developed in Loibl et al. (2010). For this model simulation, all relevant meteorological variables such as temperature, precipitation, solar radiation or snow are available on a daily basis with a spatial resolution of 10×10 km. Bias correction using the quantile mapping technique (Déqué, 2007) for localization on a 1×1 km grid was based on gridded observational data sets (Haiden et al., 2009; Schöner and Dos Santos Cardoso, 2004). For all indicators of the type "peak over threshold" (e.g. heat days defined as maximum temperature of 30 °C or higher), a statistical relationship between monthly mean values and indicator values was derived from observational data and applied to the localized scenario data (Formayer et al., 2015). This method was used to specify the range that the ensemble of GCMs and RCMs allows to derive for climate-dependent indicators.

In total, 63 impact relevant indicators were identified jointly by the interdisciplinary team, most of them being of the type "peak over threshold". For precipitation, indicators for dry conditions (consecutive dry days) or for heavy precipitation (number of days with precipitation exceeding certain thresholds) were derived. Climate change information for these was provided both at the 1×1 km grid (for impact models drawing on this resolution) and aggregated at the NUTS 3 level (since most socio-economic data and models operate at this geographical scale) allowing for a spatially consistent coupling of climate and socio-economic impact models. For data reported at the NUTS 3 region level, in addition to the spatial mean value, also (in particular for temperature) minima and maxima for the region (governed by also different elevations within the region) were provided. See Formayer et al. (2015) for full details for the climate scenario calculations, and the respective online material of this reference for the full list of climate-dependent indicators.

The socioeconomic scenarios

As climate change impacts are also strongly co-determined by socio-economic development, consistent assumptions (in the form of scenarios) for socioeconomic developments have to be applied across impact fields. For scenarios at the global level, this necessity was pointed out by Moss et al. (2010) in general, and by van Vuuren et al. (2011) in the context of the representative concentration pathways (RCPs). For the global level, van Vuuren et al. (2014) developed the matrix framework with RCPs on one axis and socioeconomic pathways at the other, and O'Neill et al. (2014) suggest that the space these latter pathways should span is defined by the challenges to mitigation on the one hand and to adaptation on the other hand. Kriegler et al. (2014) link these shared socioeconomic pathways (SSPs) back in more detail to the RCPs by presenting the relevant assumptions particularly on climate policy to drive these pathways.

We draw from this development of shared socioeconomic trajectories and use their SSP2, denoting "intermediate challenges" along both dimensions of mitigation and adaptation, as our reference socioeconomic trajectory. Consistent with the SSP2 of O'Neill et al. (2014), we provided all sector experts with a shared socio-economic pathway, based on Hanika (2005, 2010), and corresponding detailed figures for the core economic (e.g. 1.65% GDP growth p.a.), demographic (e.g. 0.27% population growth p.a.), land use (e.g. forests, meadows and settlements expand in the north–east–south crescent at the cost of arable land, within which further intensification will take place) and (qualitatively) technological development in

Austria. These parameters were chosen consistent with our climate (i.e. emission) scenario reported above. While this reference scenario is a "medium" one, the Austria we expose to climate change by 2050 is significantly different from today's: its population is older and its public and private infrastructure density is higher – to name just two factors that influence future vulnerability. Sectoral consistency for these shared set of parameters was ensured by identifying one field expert team responsible for specification of each of the parameter values and for achieving consensus with other teams using this parameter as well (e.g. the agriculture team was responsible for land use development parameters, the economic team for economic overall growth, etc.). For a detailed characterization of the SSP specification demands and communication structure to ensure sectoral consistency, see König et al. (2015).

Sectoral impact modelling: the direct costs of climate change impacts

The first step in sectoral impact modelling is the identification of relevant impact chains and – wherever possible – their detailed description. The next step is to select a suitable (bio)physical impact model or method, which will in general be at least one for each impact field (Fig. 1). It also needs to be decided which impact chains can be assessed in quantitative terms and which cannot.

In the present study, we used agricultural yield models, forestry yield models or energy-economic models to assess those impact chains which could be quantified in the respective impact fields (see Table 1). As an alternative to such optimization and/or simulation models, econometric regression models were used to derive an impact function which relates, e.g. a time series of overnight stays to snow availability (see impact field Tourism in Table 1), or relates a time series of road damage data to daily precipitation at NUTS 3 level (see impact field Transport in Table 1), or the number of premature deaths to a particular heat day indicator (so called Kyselý days; Kyselý, 2004) (see impact field Human Health in Table 1). If such an impact relationship cannot be estimated but there is sufficient sectoral base data, past trends can be extrapolated and adjusted by a mark-up factor to take account of climate change. This approach has been, e.g. implemented for the impact fields Water Supply and Sanitation as well as Cities and Urban Green. If neither data nor a suitable model is available, value transfer from other countries can be applied. In the Austrian case study the latter was combined with local specific climate scenario data to evaluate labour productivity losses in the impact field Manufacturing and Trade. For one impact field, Ecosystems and Biodiversity, it was not even possible to apply value transfer as the relevant data for such a transfer was not available in sufficient quality for Austria (Zulka and Götzl, 2015).

Table 1
(Bio)physical impact evaluation models and methods used by impact field in Austria.

Impact field	Impact chains	Model/Method used
Agriculture	Crop productivity of main crops (grain maize, winter wheat, winter rape, soybean, temporary grassland) and grassland due to changes in temperature and precipitation	Regression analysis based on biophysical process model EPIC (Izaurralde et al., 2006) and farm optimization model PASMA (Schmid, 2004).
Forestry	Biomass productivity in commercial production forests due to changed precipitation and temperature, bark beetle disturbances on productivity of commercial forests and protection functionality of protection forests	Estimation of productivity changes based on forestry revenue model PICUS 3G (Schörghuber et al., 2010); damages from spruce bark beetles estimated with FISCEN scenario model (Seidl et al., 2009, 2011); impact of bark beetle disturbances on protection functionality based on expert guess (Lexer et al., 2015).
Human Health	Change in mortality due to heat waves and continuous temperature increases	Statistical relationship between excess mortality and Kyselý days on NUTS3 level (Haas et al., 2015 based on Moshammer et al., 2006).
Water Supply and Sanitation	Water supply: Lower yield of springs and drying cracks in the soil; lower ground and surface water recharge; turbidity of spring water; change of withdrawal Sanitation: Increase of wastewater volume; increase of sewer flooding; sewer sedimentation during dry weather	Extrapolation of past trends from existing data and mark-up for climate change impacts (Neunteufel et al., 2015, based on Neunteufel et al., 2009, 2011, 2012a, 2012b, 2013, Ertl et al., 2013).
Buildings: Heating and Cooling	Increased cooling energy demand in summer, decreased heating energy demand in winter	Simulations with Invert/EE-Lab, a dynamic bottom-up model integrating building stock, heating and cooling for Austria (Kranzl et al., 2013, 2014; Müller, 2015; Müller et al., 2010).
Electricity	Change in annual and seasonal hydropower, wind and PV electricity generation; lower availability of cooling water for thermal and nuclear power plants; change in generation mix and/or reduction in reliability of the electricity system	Simulations with HiREPS, a dynamic electricity sector dispatch optimization model for electricity and heating (Kranzl et al., 2014, 2015; Totschnig et al., 2013, 2014).
Transport	Road damages due to increase in floods, landslides and mudflows	Regression analysis on past damage events and costs at NUTS 3 level (Bednar-Friedl et al., 2015).
Manufacturing and Trade	Productivity losses of workers due to heat and humidity	Statistical relationship between Wet Bulb Globe Temperature (WBGT) index and worker productivity, here differentiated by NUTS3 region, subsector, outdoor/indoor and work intensity (based on Kjellstrom et al., 2009).
Cities and Urban Green	Improved prevention against loss of climate comfort in urban environments – investments in and maintenance of additional parks, additional tree planting	Extrapolation of past trends from existing data and mark-up for climate change impacts (Loibl et al., 2015, based on Gill et al., 2007).
Catastrophe Management	Building damages due to riverine floods	Two catastrophe modelling approaches are applied for spatially disaggregated riverine flooding damages with different return periods. The HORA based approach builds on detailed risk zones and insurance data on building damages and provides average annual losses (Prettenthaler and Albrecher, 2009); the second model uses a hybrid convolution approach (Hochrainer-Stigler et al., 2014) which builds on results of the LISFLOOD model and estimates from the ClimateCost project (Feyen and Watkiss, 2011; Rojas et al., 2013) and on results of the AdamCost project which is based on flood hazard maps (Kundzewicz et al., 2010; Lugeri et al., 2010).
Tourism	Changes in winter and summer tourism demand	Regression analysis for overnight stays at NUTS 3 level by season; costing based on regression and tourism satellite accounts (Köberl et al., 2015).

Following Metroeconomica (2004), different methods can be used to translate (bio)physical damages of climate change into economic impacts for each impact chain (see Fig. 1). We find that five types of economic impact channels suffice to translate (bio)physical into economic impacts: change in the production cost structure, in productivity, in final demand, in investment, and in public expenditures (Fig. 2). The production cost structure changes, for example, when in agriculture other inputs (irrigation) or other input quantities (more fertilizer) are required because of climatic change. The productivity of a sector can be affected, e.g. when labour productivity is reduced in manufacturing due to a hotter climate. Alternatively, final demand can be affected, e.g. when demand for winter tourism declines in response to reduced snow availability. Investment expenses may change, e.g. additional investment in wastewater management may be necessary to account for the potential of larger flash floods in cities. Finally, public expenditures can be affected, e.g. due to disaster relief for flood damages. When the impacts of climate change cannot be estimated directly, preventive expenditures can be used as a proxy, such as costs of the creation of additional park areas in cities to avoid an increase in the urban heat island effect under climate change.

As a last step in the sectoral costing, all costs are aggregated from smaller spatial scales, such as NUTS 3 or 1×1 grid level, to the national scale as this is the level of analysis for the macroeconomic assessment. The level of spatial disaggregation both possible and necessary vastly differs across models. Many impacts are governed by very local conditions – e.g. agricultural harvests governed by local temperature, soil quality and slope – and the agricultural biophysical process impact model thus works at the 1 km pixel resolution (Mitter et al., 2015), requiring also the resolution of climate-indicators at this highly disaggregated level. Socioeconomic data are usually not reliably available below the NUTS 3 level (Austrian NUTS 3 regions have a size of approximately 2500 km^2), often even only at the national level. Thus biophysical impacts are evaluated at the finest resolution possible (e.g. for agriculture at the 1 km $\times$ 1 km grid, e.g. for labour productivity impact which is relying on socioeconomic labour data at the NUTS 3 level), evaluated in economic terms, and the economic net effect then is translated to the respective sector aggregated at the national level for economic sectoral interaction modelling, with the latter not available below the national level at a sufficiently high sectoral disaggregation.

While (bio)physical impact results are thus mostly available at a spatially highly disaggregated level (as reported in Steininger et al., 2015a), the level of spatial aggregation for the economy-wide assessment reported in the next subsection, which builds on input output and international trade tables generally available only on the national scale, is the country level. For matters of space limits in results we report in this article we focus on the national level only.

Macroeconomic impact modelling

The macroeconomic analysis of the climate change impacts in the different impact fields is conducted within a computable general equilibrium (CGE) model for Austria. A CGE analysis is based on input–output tables and international trade data, consumer data and government balances and allows for the detailed assessment of climate change impacts on specific sectors, households and governments, and the overall economy (see e.g. OECD, 2015). Because of this larger sectoral detail, CGE models are better equipped than the more commonly applied IAMs to assess the different consequences of climate change which might be positive for some sectors or groups but negative for others.

The Austrian CGE model operates on the national scale and distinguishes 41 sectors with a base year of 2008 (date of the latest available input-output table). Sectoral production is represented by nested production functions, which represent easier substitutability within capital and labour as well as within energy products, and more difficult substitutability between these inputs and all other intermediate inputs. Households receive wage and capital income and spend income on energy and other consumer goods. As for production, substitutability between energy and non-energy products is lower than within those two consumption categories. The government collects taxes on labour, capital, production, exports and value-added, and spends revenues on transfers to households, unemployment benefits, and government consumption. Austria is modelled as a small open economy and all other world regions are reflected by their trade flows to and from Austria.

Table 2 illustrates how the climate change impacts are implemented for all impact fields except for Human Health in the CGE model. For instance, the agricultural sector in Austria benefits from longer growing seasons, which translate into higher productivity but also require higher inputs such as fertilizers (Mitter et al., 2015). In contrast, the forestry sector is affected negatively by climate change due to a higher pest pressure and lower productivity in commercial forests, and thus modelled as lower capital and labour productivity; the forestry sector is also affected by higher investment into protective forests, which are compensated by higher government subsidies (Lexer et al., 2015). For the impact field Human Health it was not possible to estimate the economic consequences of morbidity impacts, e.g. in terms of higher admission rates of hospitals (Haas et al., 2015); it was however decided to add the costs of mortality (life years lost) in the final analysis step (see the subsection *Weather and climate-related economic impacts* in section Results below).

As our static CGE model reflects annual monetized flows, investments need to be annualized, taking also into account whether the investment is required one-time or permanently. We furthermore assume that total investment in the economy is fixed (in line with a constant exogenous saving rate) such that climate change-induced investments are diverted from other investment options in the economy.

In addition to taking account which costs arise in which activity field, it is furthermore necessary to specify who is paying for these costs, e.g. whether costs are covered in the respective sector and (partly) passed onto consumers by means of higher prices, or whether government subsidies/expenditures are increased. The default option is that costs are covered by each sector, but for specific expenditures it is assumed that subsidies or transfers are introduced, as indicated by an "x" in the bottom row of Table 2 ("public expenditures"). For full details on the CGE model and the implementation of impact chains, see Bachner et al. (2015a,b).

Range-of-impact analysis

As the analysis of future climate change impacts is connected to significant uncertainties of various types (e.g. Heal and Millner, 2013), range-of-impact analysis is crucial. We here suggest a bottom-up approach to identify the most relevant uncertainties for each impact field. Heat-related premature deaths may be most dependent upon the extent and duration of summer heat waves and share of the elderly in the population, while winter tourism will be most dependent upon winter precipitation and temperatures, and transport system damages will be most dependent upon the extension of the transport network and on convective extreme weather events triggering flooding or mudslides.

It is therefore necessary that the most relevant parameters driving damages across the impact chains of each impact field are to be identified and varied. In our application for Austria, these parameters were identified both from literature review and previous experience of each impact field team with their impact models. Varying

Impact field	Costing method		Exposure unit		Costing unit
Agriculture	Change in agricultural productivity	=	Change in average annual crop and grassland forage yields	x	Average commodity prices
Agriculture	Change in production costs	=	Change in management techniques	x	Average variable production costs (e.g. fertiliser costs)
Agriculture	Change in public expenditures (change in agricultural policy premiums)	=	Change in management techniques	x	Average agricultural policy premiums
Forestry	Change in forest productivity	=	Change in annual timber volume production	x	Average timber prices
Forestry	Change in productivity (increase of bark beetle damage in production forests)	=	Change in salvaged area	x	Average afforestation costs
Forestry	Change in productivity (increase of bark beetle damage in production forests)	=	Change in salvaged timber volume	x	Average reduction in contribution margin
Forestry	Replacement cost (increase of damaged area in protection forests)	=	Change in damaged area	x	Average cost required to restore protection functionality
Water Supply and Sanitation	Change in final demand	=	Change of demand for water and associated number of assets that need to be adapted	x	Costs of water production and adaptation of assets
Water Supply and Sanitation	Change in production cost	=	Number of assets that need to be adapted due to changes in water availability, quality and volume of wastewater	x	Cost of adaptation of assets and changed operating expenditure
Water Supply and Sanitation	Replacement cost	=	Change in number of infrastructure damage events	x	Average repair cost per infrastructure damage event
Buildings: Heating and Cooling	Change in final demand	=	Change in final energy demand for heating and cooling by energy carrier	x	Price of energy carrier used for heating and cooling
Buildings: Heating and Cooling	Change in final demand	=	Change in number of buildings equipped with AC by building category	x	Average specific investment costs of AC per building by respective building categories
Electricity	Change in final demand	=	Change in final demand for electricity for heating and cooling	x	Average electricity price
Electricity	Change in production cost	=	Change in electricity generation mix	x	Cost of respective electricity generation technologies
Transport and Mobility	Replacement cost	=	Change in number of damage events	x	Average repair cost per damage event
Manufacturing and Trade Services	Change in labour productivity	=	Change in labour productivity of (part of) total labour force	x	- Average wage per employee - Hourly GDP per employee
Cities and Urban Green	Preventative expenditure	=	Change in required park area [km^2] to compensate for increased heat	x	Investment and maintenance cost of park area per km^2
Catastrophe Management	Replacement costs (losses due to catastrophes)	=	Affected number of buildings or infrastructure	x	Average damage according to return period of floods (damage function)
Tourism	Change in final demand	=	Change in overnight stays by season and region	x	Average expenditure of visitor per overnight stay by season and region

Fig. 2. Economic costing methods applied by impact field in Austria. Source: Bachner et al. (2015a).

Table 2
Implementation of climate change impacts in the Austrian CGE model.

Change in. . .	Impact field									
	Agriculture	Forestry	Water Supply and Sanitation	Buildings: Heating and Cooling	Electricity Supply	Transport	Manufacturing and Trade	Cities and Urban Green	Catastrophe Management	Tourism
production cost structure	x	x		x	x					
productivity	x	x					x			
final demand			x	x	x				x	x
investments		x	x		x	x			x	
public expenditures		x						x	x	

these parameters is subsequently used to supply scenarios that are referred to as "damage enhancing" or "damage diminishing" respectively. This allows for the definition of a matrix as given in Table 3 for each impact field.

To integrate impact field specific uncertainty scenarios to a consistent overall uncertainty analysis, it needs to be acknowledged that different parameters are relevant for damage enhancement or diminishment, and possibly in different directions across impact fields. Thus, it is not permissible to just add up lowest (or respectively highest) damages per impact field to get a meaningful total. Rather we need to investigate which of the impact field scenarios are consistent and consider for an aggregate number (a) only those impact field scenario assumptions that are consistent and (b) the matching scenario of other impact fields; i.e. for an aggregate high damage scenario this may include high damage scenarios of some impact fields, but the low damage scenario of others (e.g. rising temperature induces higher damages in labour productivity, but lower ones in heating costs). The consideration (b) also implies to first add up consistent scenarios before being able to identify which is the overall lower damage and which the higher damage scenario.

Communication strategy

The last step in the assessment framework relates to a communication strategy involving the translation of modelling results into user-tailored products, which inform stakeholders in a non-scientific language on the impacts both for each impact field and overall, but also point to modelling assumptions and limitations. For the case-study example of Austria these products consisted of fact sheets (a two-pager for each sector and a 6-pager for overall results) as well as a narrative-document employing informed storytelling to raise awareness for adequate concern (Steininger et al., 2015c). All documents can be retrieved from http://coin.ccca.at. Both types of products were developed in a dialogue between scientific impact field specialists and journalists. A series of workshops enabled a stakeholder dialogue based on these products, which triggered a process of working group meetings.

Table 3
Scenario definition for range-of-impact analysis.

	Climate change scenario		
Socioeconomic baseline	Low-range	Mid-range	High-range
Damage diminishing			
Reference		mid-range/ref[a)]	
Damage enhancing			

[a)]results are contained in two sections:
for the mid-range reference scenario, see section *Economic impacts induced by future climate change: results for the mid-range reference scenario*;
for all other matrix fields, results are reported in section *Weather and climate-related economic impacts.*

Results

Economic impacts induced by future climate change: results for the mid-range reference scenario

From an economy-wide perspective, climate change leads not only to direct effects within each impact field but also to indirect effects because of sectoral linkages (European Environmental Agency, 2007; Merz et al., 2010).

The impact chains modelled for future climate change lead to GDP losses (originating as net negative effects in the impact fields Electricity, Forestry, Tourism, and Catastrophe Management) equal to –0.15% in 2030 and GDP gains (originating as net positive effects in impact fields Agriculture, and Buildings: Heating and Cooling) equal to +0.08%, both numbers compared to the baseline scenario without climate change (Fig. 3). The overall net effect on GDP in 2030 is therefore a GDP loss of 0.08% (see "All impact fields (net)" label in Fig. 3). The net GDP effect in 2050 is a net loss of 0.15% which results from a gross GDP loss of 0.24%, partly compensated by a gross gain of 0.09%. Across impact fields, the strongest negative GDP impact is originating in the impact field Forestry because of lower yields and additional investment into protective forests, the second strongest negative impact originates in the impact field Electricity Supply because of reduced water availability in hydropower plants. The strongest positive GDP effect emerges in the impact field Agriculture due to higher yields, while reduced energy use from heating in the impact field

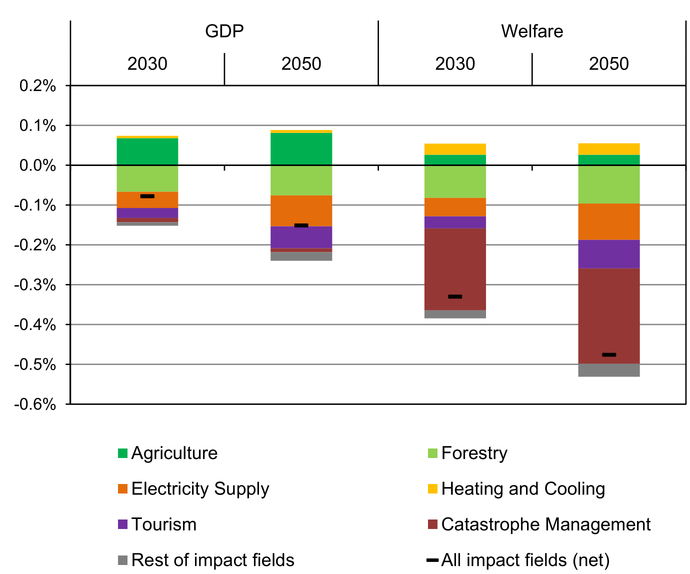

Fig. 3. Decomposition of annual GDP and welfare effects of climate change (relative to baseline with reference socioeconomic development) by impact field and in total (2030 = period 2016–2045; 2050 = period 2036–2065).
Rest of impact fields: Water, Transport, Manufacturing and Trade, Cities and Urban Green. Calculations based on Bachner et al. (2015b), figure 21.3.

Buildings: Heating and Cooling is largely compensated by larger energy use for cooling leading to an only slightly positive effect on GDP.

Compared to changes in GDP, the net loss in welfare is three to four times higher in both periods of analysis: 0.33% in 2030 and 0.48% in 2050. The reason for this stronger negative effect on welfare is that, e.g. reconstruction of buildings and equipment has a positive impact on GDP but reduces welfare because reconstruction of buildings and equipment can only reestablish assets that were available before climate change induced destruction (and in this respect therefore is welfare neutral), but these expenses do reduce available income for other consumption (inducing a reduction in welfare). Moreover, due to the requirement that higher government expenditures cannot increase the public deficit, higher expenditures for disaster management are compensated by lower government consumption of health, education, and other public services. Thus, while climate driven natural disasters (impact field Catastrophe Management) have a net negative impact on GDP of only small size, there is a much stronger negative effect on welfare.

A more detailed picture of the total GDP and welfare effects can be gained by looking into sectoral effects caused by the combined impact originating in all impact fields, with impacts split up by the economic sectors these ultimately hit, i.e. by the 41 sectors of the CGE model (Fig. 4). Fig. 4 therefore provides a ranking of those economic sectors which are affected most positively to those economic sectors which are affected most negatively, triggered by the combined impacts across all impact fields. The strongest positive effect is found in the construction sector due to reconstruction activities of buildings and public infrastructure such as electricity supply infrastructure, water and sewage system infrastructure, or transport infrastructure. Positive output effects emerge also for the agricultural sector and in motor vehicle trade and repair. Sectoral output losses occur in the energy sector, in forestry, in health and other public services, as well as in consumer goods related sectors, such as wholesale and retail trade, accommodation, and rest of services (Fig. 4).

Fig. 4 also illustrates that it is not only the economic sector which is directly affected by climate induced changes in the impact field which experiences an increase or decline in output but also other economic sectors because of supply and demand linkages and price effects. A second, and in many model studies neglected

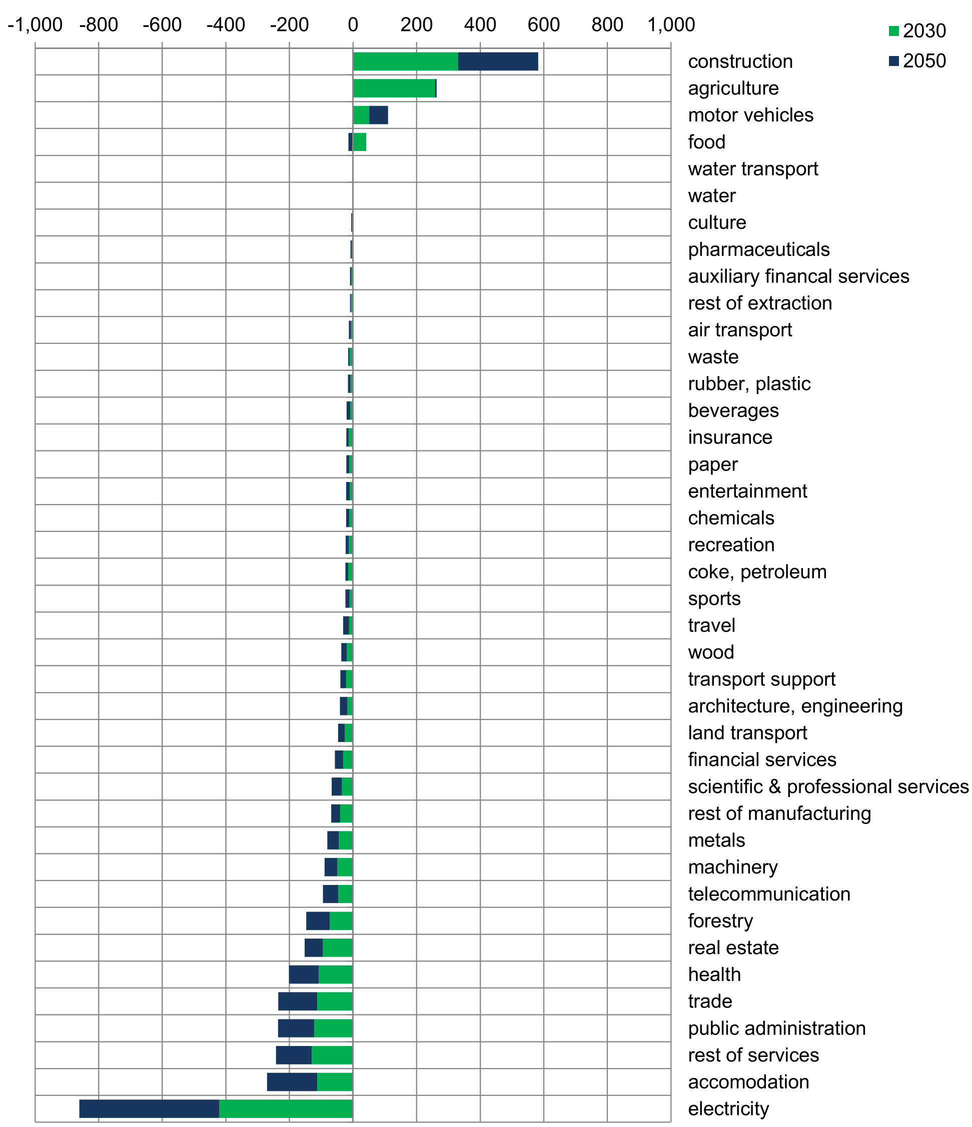

Fig. 4. Sectoral output effects of all impact fields in mio. € (2008 prices) in 2030 (relative to baseline with reference socioeconomic development) and additional effects in 2050 (i.e. beyond those in 2030).
Calculations based on Bachner et al. (2015b), figure 21.4; note that these are changes in output quantities by sector, not changes in value added (their sum thus does not add up to the GDP effect).

Table 4
Climate and weather induced damages for Austria up to mid-century, currently quantifiable impact chains only, mid-range/reference scenario and low-impact- and high-impact-scenario levels for average annual totals (for periods 2016–2045 and 2036–2065).

Damage in €m p.a. (2010 prices)	∅ 2001–2010					
(A) Stock of damages						
Damage observed to date (market and non-market)	**850–1090**					
Annual average of extreme weather event damage (MunichRe, only larger damage, Ø for period 2001 to 2010)	705					
Heat induced premature deaths	145–385					
Evaluation using Value of Statistical Life (€ 1.6m per SL)	385					
Evaluation using Value of Life Years Lost (€ 63000 per LYL)	145					
	∅ 2016–2045			∅ 2036–2065		
	Low-impact	**Reference**	**High-impact**	**Low-impact**	**Reference**	**High-impact**
(B) Additional Future damages						
Damage induced by future climate change	890	**995**	1211	1825	**1955**	2280
Welfare loss (resulting from consistent low and high climate change impact scenarios across impact fields)						
Additional damage induced by future socioeconomic change	268	**270**	314	800	**825**	1080
Energy additional investment		99			298	
Road infrastructure additional investment		8			20	
Riverine flooding additional damage		163			507	
Heat induced premature deaths	82–210	**95–255**	580–1535	285–640	**570–1300**	1840–4350
Evaluation using Value of Statistical Life	210	255	1535	640	1300	4350
Evaluation using Value of Life Years Lost	82	95	580	285	570	1840
(C) Total annual average						
(Comprising current level plus future additional damages)	2090–2458	**2210–2610**	2955–4150	3760–4355	**4201–5170**	6050–8800

Data based on Steininger et al. (2015b): tables 22.1 and 22.2.

mechanism, is that government expenditures are diverted to disaster compensation payments, leading to government expenditure cuts of other expenses like education or health. Because of these indirect effects, the total macroeconomic effect can therefore be much larger than the direct effect within the respective sector (Hallegatte et al., 2007). When looking into each impact field separately, we can quantify the cross-sectoral amplification of damages: e.g. heat-induced productivity losses in manufacturing translate to damages across the whole economy at the three to fourfold scale (Urban and Steininger, 2015), losses in overnight stays in winter tourism translate to 60% higher overall economic damages (Köberl et al., 2015), or damages to Austrian road transport translate to about two to three times higher overall economic costs (Bednar-Friedl et al., 2015).

Weather and climate-related economic impacts

Various economic sectors are exposed to weather-induced damages due to weather variability itself (without climate change). Sector and macro-stakeholders are thus interested not only in the damages foreseen due to additional climate change but also in their sum with climate- and weather-induced damages when the climate does not change, as only this sum marks the comprehensive challenge for society. Climate change can (and usually will) change both the mean of relevant climate dependent indicators as well as their variability, and both effects are relevant for future damages (see e.g. Lazo et al., 2011, Töglhofer et al., 2012 or Prettenthaler et al., 2016).

We thus expand our analysis to first include the level of current weather- and climate-induced damages, and, second, also consider one non-market damage, namely heat wave induced premature loss of life. This second extension is one beyond the damage categories covered in the previous subsection *Economic impacts induced by future climate change: results for the mid-range reference scenario* within the macroeconomic model, where the quantitative evidence for linking these numbers to economic consequences had to be considered to be too weak to be included in the model analysis. Nevertheless these numbers have to be accounted for at least in their pure form (i.e. without considering their macroeconomic feedbacks) and are thus included here.

A conservative estimate is to consider an annual average of the last decade of climate- and weather-induced extreme events and premature deaths. Building on Munich RE (2014), which supplies the most comprehensive database on weather- and climate-related damage for Austria, we find that across the past decade (2001–2010), the annual average damage related to large and medium events in Austria (categories 5 and 6 on a 6-level-scale) was €$_{2010}$ 705 million (m), equivalent to slightly above 0.25% of GDP. According to Munich RE NatCatService data, the climate and weather related premature death toll in Austria over the last decade (2001–2010) was 411 persons, of which 334 were due to heat, 38 due to avalanches, and the remaining 39 due to floods and storms. To monetize these premature deaths (at their annual average level), we can build upon either the Value of Statistical Life (VSL), or also acknowledge in more detail the age at which life is lost, applying the concept of Life Years Lost (LYL). Using the unit values of Watkiss (2011), i.e. 1.6 million € for the VSL and 63,000 € per LYL, we get the range of monetary evaluation given in Table 4, section A. Adding these, we identify a stock of climate and weather induced damages in Austria (the 'adaptation deficit') at an annual average of €$_{2010}$ 1 billion for the first decade in the 21st century (bold number in Table 4, section A).

This is a conservative estimate, as it captures only some of the impacts of extremes and ignores the effects of the current climate and its inter-annual variability on many other areas, such as crop productivity, winter heating and summer cooling, water flows and availability. Also, these monetary estimates only include direct damages observed. Thus, neither the indirect disruption or follow-up costs, nor further non-market impacts (such as biodiversity losses, health inconveniences) are included. Including the additional effects from indirect and non-monetary areas, as well as macro-economic costs, would increase these estimates further, possibly by 25–100% (see e.g. Hallegatte et al., 2007).

The third expansion of our analysis concerns weather and climate related damages induced by socioeconomic development, i.e. damages that would occur also under a stable climate. In our application to Austria we monetized four such impacts (covered in Table 4, section B), where three of them are market damages. The trend towards electrification, and in particular the foreseen higher share of air conditioning (even without additional climate change), requires additional supply investment to meet a different peak load structure. The foreseen expansion of the road network raises weather- and climate-induced damages on the road network even if no further climate change would occur. Finally, the rise in real values of houses increases riverine flooding damages. For the non-market damage of premature deaths, Table 4 states the overall number combining climate and socioeconomic change, with the range resulting from the two monetization approaches used (Haas et al., 2015; Steininger et al., 2015b).

The fourth expansion is not in terms of types of costs covered, but in looking at uncertainties and the thus arising ranges of potential monetary damages. These are derived from varying the scenarios for each impact sector across the two dimensions of socioeconomic development and climate as given in Table 3. The climate scenarios are spanned by the combination of 17 GCMs and 14 RCMs and respective RCPs (see the section *The climate scenarios and climate-dependent indicators derived*), allowing the derivation of the range for each climate dependent indicator. For the human health relevant climate indicator, for example, the number of Kyselý days (days within a period of at least three days above a certain temperature threshold) is derived for the coldest and warmest climate scenario. Parameters of socioeconomic development are varied across a range considered plausible by the respective impact field team. Note that the latter has been achieved without assigning likelihoods to specific scenarios. The combination of socioeconomic and climate scenarios allows for the derivation of low-impact and high-impact damages for each impact field. The methodological section (subsection *Range-of-impact analysis*) did report how to relate field impact values to derive aggregate low- and high-impact values. Table 4 (section B low-impact and high-impact columns) report those values. They mark a range around the reference values in Table 4 section B, which for "Damage induced by future climate change" indicate the damage values as reported in the section *Economic impacts induced by future climate change: results for the mid-range reference scenario*; the other reference values have been derived in the present section along each of the extensions of analysis.

It is illustrative to take a closer look at one impact field for its range of damages. A significant share of damage is accounted for by heat-induced premature deaths. While the damage number here also depends on which monetary unit is chosen for the valuation (VSL or LYL, see Table 4), as we have discussed before, we find that a far larger fraction of the range is determined by climate uncertainty, and the largest fraction is determined by which socioeconomic scenario we choose. The latter is varied from "10% of the population aged 65+ reduce their risk by 50% due to air conditioning" (the "intermediate" case) to "20% to do so" (the low damage case) and to "no additional air conditioning" (the high damage case). For full details on health impacts, see Haas et al. (2015).

These results indicate how rich the information from such an exercise is for adaptation in each impact field – just take the example on premature deaths and its implications for social policy enabling access to sufficient resources for adequate (also environmentally benign) in-door temperature conditioning. The results also allow stakeholders interested in the cost of inaction for Austria to look at the economy-wide totals to prepare for future budget demands and other consequences.

Discussion and conclusions

The starting point of this article was that most climate impact assessment studies provide a partial picture by either focusing on only one or a subset of climate sensitive sectors or by having an economy-wide perspective but a very narrow coverage of climate change impact chains. We demonstrate that this gap can be addressed by looking jointly into all impact fields for a country, by using consistent scenario assumptions and a common costing framework, and by linking a set of (bio)physical impact models and methodologies to a computable general equilibrium model. When applying this framework to the case study of Austria, we find that – based on impact chains where economic assessments can already be made available – six impact fields are responsible for the lion's share of macroeconomic effects of climate change in Austria by 2050. These are Catastrophe Management, Agriculture, Forestry, Electricity Supply, Tourism, and Heating and Cooling. The remaining four impact fields (Water Supply and Sanitation, Transport, Manufacturing and Trade, Cities and Urban Green) are of considerable smaller relevance. Overall, macroeconomic impacts are found to be a loss of 0.15% of GDP in 2050. The net welfare loss, however, is three times higher: while climate change damage cleanups require reconstruction, thus contributing positively to GDP, this just re-establishes the earlier welfare level but at the same time requires an alternative use of budgets, reducing expenses that earlier were contributing to welfare.

One request by stakeholders was that not only the impacts of *additional* future climate change were relevant for decision making but also total future damages. Model-based results reported in the previous paragraph and indicating future damages due to additional climate change were therefore complemented with data on current weather and climate-related damages due to weather variability. Second, for decision making it is important to determine which part of future damages is due to climate change and which to socioeconomic change, as both open different fields of action for decision makers. In terms of socioeconomic change, for example, decision makers might want to steer land use change or infrastructure development in a way that future damages can be mitigated. Third, decision makers are also interested in economic values of damages even if – due to data limitations – these cannot be assessed for their macroeconomic implications. In the current study, this was the case for health effects, where the effects on premature deaths had been evaluated but not their macroeconomic consequences arising from impacts such as changed hospitalization rates. As two alternatives, the monetary value of health effects was approximated by the value of statistical life measure and by the measure of life years lost.

To assess ranges-of-impacts, the starting point is the aggregate impact evaluation for one mid-range climate and a reference socioeconomic scenario across all impact fields. We explore the range of potential damages based on the appropriate combination of scenarios that enhance (or diminish) damages in specific impact fields. For example, longer summer heat waves and increasing agricultural harvest losses can be consistent with higher winter temperatures that could raise winter tourism losses but will induce larger heating cost savings. Such sector specific uncertainty analysis is crucial for explicit adaptation, but also for socioeconomic development to reduce vulnerability. Our approach in the uncertainty dimension is limited in that confidence intervals are not supplied for these ranges, at least not at the overall aggregate level. More precisely, for each individual impact field we can give confidence intervals for damage values, but separate for each socioeconomic scenario. This is helpful, detailed information. For example, our analysis shows that prohibiting construction in flood-prone zones (in zones with a 200 year return period of flooding) – which constitutes one particular socioeconomic scenario, also indicating one strand of potential adaptation policy – does reduce both the 95% and 99% quantile of riverine flooding damages to buildings by roughly half by the end of the century (Prettenthaler et al., 2015). As we decide not to assign likelihoods to the socioeconomic scenarios, no confidence intervals for a combination of results across such socioeconomic scenarios, and thus for the impact field as a whole (or the aggregate number across impact fields), can be derived.

While confidence intervals for damages can thus only be supplied within socioeconomic scenarios of each impact field, the impact field totals – both their mean values and ranges – and their economic interaction results at the aggregate level do supply crucial additional information. These results can inform, on the one hand, public stakeholders such as ministries and governmental departments which need to allocate financial resources across policy areas, but also among different impact fields. Second, sectoral stakeholders can derive insights on the macroeconomic effects of climate change impacts triggered in their field. For instance, heat induced productivity losses in manufacturing affect other sectors strongly such as transportation and construction, or losses in overnight stays in winter tourism reduce intermediate supplies by the accommodation and food sector. These effects can be used as leverage points for private and public sector participation in financing adaptation in their respective impact fields.

Note that there are clear limitations in our approach that would be rewarding to address in future research. For two of the impact fields (Human Health and Ecosystems/Biodiversity) there was insufficient knowledge to include them in the macroeconomic model and thus in the macroeconomic analysis. We only included field impacts (Human Health: premature deaths) after the macroeconomic analysis (ex-post) to be covered within the overall totals. For a significant number of impact chains, no model-based quantification was available yet, and these could thus not be included. All of these were, however, clearly pointed out (most importantly also as a table in the six-page overall summary fact sheet for stakeholders).

The applied macroeconomic model (computable general equilibrium analysis) is overly optimistic in assuming perfectly informed actors (resulting in optimal individual – spontaneous – adaptation) and quickly adjusting markets (fully flexible). Moreover, optimization is undertaken for each time step and hence response to impacts is reactive and not dynamic (i.e. not in anticipation of higher future damages). Maladaptation and rigid market adjustment is therefore likely to render the totals supplied here as lower bounds. This macroeconomic analysis also focuses on flows, while climate damages often also concern stocks. This shortcoming was only addressed ex-post to the macroeconomic analysis in the derivation and reporting of the welfare indicator, also acknowledging stock changes. Reporting at the aggregate macro level may be used to conceal the fact that there are strongly divergent results across sectors, specific groups and regions in a country. This requires careful communication of results at all these levels of detail. Damages of extreme events at the aggregate level are reported only as average annual means, while the distribution of their occurrence is crucial (and available for each socioeconomic scenario by impact field). Finally, the resources limited us to restrict ourselves to the analysis of impact chains that start within the specific country of analysis. Thus we could not include climate change impacts originating in other countries and – e.g. via international markets (food prices), or by migration – incur feedback.

Having run this exercise for one country and having available the comprehensive description of the steps involved (for details per impact field, see Steininger et al., 2015a) should ease a similar endeavour for other countries. The core issue for the feasibility of such an application – or more precisely the comprehensiveness such an analysis can achieve – is the availability of researchers specialized in the respective impact fields who can specify impact chains and develop and apply the respective impact models. For any impact field where such availability is not given or is weak, the quantitative relationships would need to be established within the project, extending the time frame and raising resource demand. In addition to the work of impact modelers, the effort goes primarily to ensuring consistency by means of the common scenario definition, the derivation of scenarios for each climate-dependent indicators as identified in each impact field from the common ensemble of climate scenarios, adequate integration of economic impact evaluations by impact field into this model, the creation of and simulation analysis with the macroeconomic model, as well as the shaping of report documents each addressing one of the different audiences – scientific, business, public administration, and the general public.

Acknowledgements

This research was supported by research grant B286216 of the Austrian Climate and Energy Fund within the Austrian Climate Research Programme (project COIN). We thank the COIN research team for scientific discussion, the CCCA Climate Service Centre Austria for inspiring collaboration in the generation of dissemination products and two anonymous referees of this journal for very helpful comments.

References

Aaheim, A., Amundsen, H., Dokken, T., Wie, T., 2012. Impacts and adaptation to climate change in European economies. Glob. Environ. Change 22 (4), 959–968.
Agrawala, S., Bosello, F., Carraro, C., De Cian, E., Lanzi, E., 2011. Adapting to climate change: costs, benefits, and modelling approaches. Int. J. Environ. Res. 5 (3), 245–284.
Bachner, G., Bednar-Friedl, B., Nabernegg, S., Steininger, K.W., 2015a. Economic Evaluation Framework and Macroeconomic Modelling. In: Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F. (Eds.), Economic Evaluation of Climate Change Impacts: Development of a Cross-Sectoral Framework and Results for Austria. Springer, Cham, pp. 101–120.
Bachner, G., Bednar-Friedl, B., Nabernegg, S., Steininger, K.W., 2015b. Macroeconomic evaluation of climate change in Austria: a comparison across impact fields and total effects. In: Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F. (Eds.), Economic Evaluation of Climate Change Impacts: Development of a Cross-Sectoral Framework and Results for Austria. Springer, Cham, pp. 415–440.
Bednar-Friedl, B., Wolkinger, B., König, M., Bachner, G., Formayer, H., Offenthaler, I., et al., 2015. Transport. In: Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F. (Eds.), Economic Evaluation of Climate Change Impacts: Development of a Cross-Sectoral Framework and Results for Austria. Springer, Cham, pp. 279–300.
Biesbroek, G.R., Swart, R.J., Carter, T.R., Cowan, C., Henrichs, T., Mela, H., et al., 2010. Europe adapts to climate change: comparing national adaptation strategies. Glob. Environ. Change 20 (3), 440–450.
Bigano, A., Bosello, F., Roson, R., Tol, R.S.J., 2008. Economy-wide impacts of climate change: a joint analysis for sea level rise and tourism. Mitig. Adapt. Strat. Glob. Change 13, 765–791. doi:10.1007/s11027-007-9139-9.
Bosello, F., Roson, R., Tol, R.S.J., 2007. Economy-wide estimates of the implications of climate change: sea level rise. Environ. Res. Econ. 37 (3), 549–571.
Bosello, F., Nicholls, R.J., Richards, J., Roson, R., Tol, R.S.J., 2012. Economic impacts of climate change in Europe: sea-level rise. Clim. Change 112 (1), 63–81.
Ciscar, J.-C., Iglesias, A., Feyen, L., Szabó, L., Van Regemorter, D., Amelung, B., et al., 2011. Physical and economic consequences of climate change in Europe. Proc. Natl. Acad. Sci. U.S.A. 108 (7), 2678–2683.
Ciscar, J.-C., Szabó, L., van Regemorter, D., Soria, A., 2012. The integration of PESETA sectoral economic impacts into the GEM-E3 Europe model: methodology and results. Clim. Change 112 (1), 127–142.
Déqué, M., 2007. Frequency of precipitation and temperature extremes over France in an anthropogenic scenario: model results and statistical correction according to observed values. Glob. Planet. Change 57, 16–26.
Ertl, T., Kretschmer, F., Plihal, H., Schwarz, D., 2013. INFOSAN – Strategische Informationsbeschaffung als Basis für die mittel- und langfristige ganzheitliche generelle Sanierungsplanung von Kanalisationsanlagen in Österreich. Current research project at the University of Natural Resources and Life Sciences, Vienna. <https://forschung.boku.ac.at/fis/suchen.projekt_uebersicht?sprache_in=de&menue_id_in=300&id_in=7965> (accessed 12.08.13.).
European Commission and European Environmental Agency, 2015. The European Climate Adaptation Platform (CLIMATE-ADAPT). <http://climate-adapt.eea.europa.eu/> (accessed 12.12.15.).
European Environmental Agency, 2007. Climate change. The cost of inaction and the cost of adaptation. EEA Technical Report No. 13/2007, Copenhagen.
Federal Ministry of Agriculture, Forestry, Environment and Water Management, 2013. The Austrian strategy for adaptation to climate change. Federal Ministry of Agriculture, Forestry, Environment and Water Management, Vienna.
Feyen, L., Watkiss, P., 2011. The impacts and economic costs of river floods in Europe and the costs and benefits of adaptation. Summary of sector results from the EC RTD ClimateCost Project.

Formayer, H., Nadeem, I., Anders, I., 2015. Climate change scenario: from climate model ensemble to local indicators. In: Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F. (Eds.), Economic Evaluation of Climate Change Impacts. Development of a Cross-Sectoral framework and Results for Austria. Springer, Cham, pp. 55–74.

Gill, S., Handley, J., Ennos, R., Pauleit, S., 2007. Adapting cities for climate change: the role of the green infrastructure. Built Environ. 30 (1), 97–115.

Haas, W., Weisz, U., Maier, P., Scholz, F., 2015. Human health. In: Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F., (Eds.), Economic Evaluation of Climate Change Impacts. Development of a Cross-Sectoral Framework and Results for Austria. Springer, Cham, pp. 191–213.

Haiden, T., Kann, A., Pistotnik, G., Stadlbacher, K., Wittmann, C., 2009. Integrated Nowcasting through Comprehensive Analysis (INCA) – System description. ZAMG Report, 60 p. <http://www.zamg.ac.at/fix/INCA_system.pdf> (accessed 22.02.16).

Hallegatte, S., Hourcade, J.-C., Dumas, P., 2007. Why economic dynamics matter in assessing climate change damages: illustration on extreme events. Ecol. Econ. 62 (2), 330–340.

Hanika, A., 2005. ÖROK-Prognosen 2001–2031; Teil 2. Haushalte und Wohnungsbedarf nach Regionen und Bezirken Österreichs. Schriftenreihe / Österreichische Raumordnungskonferenz (ÖROK); 166/2, Vienna.

Hanika, A., 2010. Kleinräumige Bevölkerungsprognose für Österreich 2010–2030 mit Ausblick bis 2050 ("ÖROK-Prognosen") Teil 1: Endbericht zur Bevölkerungsprognose. ÖROK, Vienna. <http://www.oerok.gv.at/raum-region/daten-und-grundlagen/oerok-prognosen/oerok-prognosen-2010.html> (accessed 22.02.16).

Heal, G.M., Millner, A. 2013. Uncertainty and decision in climate change economics. NBER Working Paper No. 18929.

Hochrainer-Stigler, S., Lugeri, N., Radziejewski, M., 2014. Up-scaling of impact dependent loss distributions: a hybrid-convolution approach. Nat. Hazards 70 (2), 1437–1451.

Hope, C., 2006. The marginal impact of CO_2 from PAGE2002: an integrated assessment model incorporating IPCC's five reasons for concern. Integr. Assess. 6 (1), 19–56.

IPCC, 2013. Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)] Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea and L.L. White (eds.)] Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Izaurralde, R.C., Williams, J.R., McGill, W.B., Rosenberg, N.J., Jakas, M.C.Q., 2006. Simulating soil C dynamics with EPIC: model description and testing against long-term data. Ecol. Modell. 192, 362–384.

Jacob, D., Petersen, J., Eggert, B., Alias, A., Christensen, O.B., Bouwer, L.M., et al., 2014. EURO-CORDEX: new high-resolution climate change projections for European impact research. Reg. Environ. Change 14 (2), 563–578. doi:10.1007/s10113-013-0499-2.

Kjellstrom, T., Kovats, R.S., Lloyd, S.J., Holt, T., Tol, R.S.J., 2009. The direct impact of climate change on regional labor productivity. Arch. Environ. Occup. Health 64 (4), 217–227.

Köberl, J., Prettenthaler, F., Nabernegg, S., Schinko, T., 2015. Tourism. In: Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F. (Eds.), Economic Evaluation of Climate Change Impacts: Development of a Cross-Sectoral Framework and Results for Austria. Springer, Cham, pp. 367–388.

König, M., Loibl, W., Haas, W., Kranzl, L., 2015. Shared socio-economic pathways. In: Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F. (Eds.), Economic Evaluation of Climate Change Impacts. Development of a Cross-Sectoral Framework and Results for Austria. Springer, Cham, pp. 75–99.

Kranzl, L., Hummel, M., Müller, A., Steinbach, J., 2013. Renewable heating: perspectives and the impact of policy instruments. Energy Policy 59, 44–58. doi:10.1016/j.enpol.2013.03.050.

Kranzl, L., Matzenberger, J., Totschnig, G., Toleikyte, A., Schicker, I., Formayer, H., et al., 2014. Power through resilience of energy system. Final report of the project PRESENCE. Project in the frame of the Austrian climate research program, Vienna, <http://www.eeg.tuwien.ac.at/eeg.tuwien.ac.at_pages/research/downloads/PR_356_B068675_PRESENCE_FinalPublishableReport_submitted.pdf> (accessed 09.02.15).

Kranzl, L., Totschnig, G., Müller, A., Bachner, G., Bednar-Friedl, B., 2015. Electricity. In: Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F. (Eds.), Economic Evaluation of Climate Change Impacts: Development of a Cross-Sectoral Framework and Results for Austria. Springer, Cham, pp. 257–278.

Kriegler, E., Edmonds, J., Hallegatte, S., Ebi, K.R., Kram, T., et al., 2014. A new scenario framework for climate change research: the concept of shared climate policy assumptions. Clim. Change 122 (3), 401–414.

Kundzewicz, Z.B., Lugeri, B., Dankers, R., Hirabayashi, Y., Doell, P., Pinskwar, I., et al., 2010. Assessing river flood risk and adaptation in Europe – review of projections for the future. Mitig. Adapt. Strat. Glob. Change 15 (7), 641–656.

Kyselý, J., 2004. Mortality and displaced mortality during heat waves in the Czech Republic. Int. J. Biometeorol. 49, 91–97.

Lazo, J.K., Lawson, M., Larsen, P.H., Waldman, D.M., 2011. U.S. economic sensitivity to weather variability. B. Am. Meteorol. Soc. 92, 709–720.

Lexer, M.J., Jandl, R., Nabernegg, S., Bednar-Friedl, B., 2015. Forestry. In: Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F. (Eds.), Economic Evaluation of Climate Change Impacts: Development of a Cross-Sectoral Framework and Results for Austria. Springer, Cham, pp. 147–167.

Loibl, W., Züger, J., Köstl, M., Formayer, H., Schicker, I., Gobiet, A., et al., 2010. Reclip:century – a project conducting 21st century regional climate simulation runs focussing on the Greater Alpine Region. Paper presented to the EGU General Assembly 2010, Vienna, Austria, 2–7 May 2010, p. 11752.

Loibl, W., Tötzer, T., Köstl, M., Nabernegg, S., Steininger, K.W., 2015. Cities and urban green. In: Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F. (Eds.), Economic Evaluation of Climate Change Impacts. Development of a Cross-Sectoral framework and Results for Austria. Springer, Cham, pp. 323–348.

Lugeri, N., Kundzewicz, Z.B., Genovese, E., Hochrainer, S., Radziejewski, M., 2010. River flood risk and adaptation in Europe – assessment of the present status. Mitig. Adapt. Strat. Glob. Change 15 (7), 621–639.

Meissner, C., Schädler, G., Panitz, H.-J., Feldmann, H., Kottmeier, C., 2009. High-resolution sensitivity studies with the regional climate model COSMO-CLM. Meteorol. Z. 18 (5), 543–557. doi:10.1127/0941-2948/2009/0400.

Merz, B., Kreibich, H., Schwarze, R., Thieken, A., 2010. Assessment of economic flood damage. Nat. Hazard Earth Sys. 10, 1697–1724.

Metroeconomica, 2004. Costing the impacts of climate change in the UK: overview of guidelines. UKCIP Technical Report. UKCIP, Oxford.

Mitter, H., Schönhart, M., Meyer, I., Mechtler, K., Schmid, E., Sinabell, F., et al., 2015. Agriculture. In: Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F. (Eds.), Economic Evaluation of Climate Change Impacts: Development of a Cross-Sectoral Framework and Results for Austria. Springer, Cham, pp. 123–146.

Moshammer, H., Hutter, H.P., Frank, A., Geresdorfer, T., Hlava, A., Sprinzl, G., et al., 2006. Einflüsse der Temperatur auf Mortalität und Morbidität in Wien. Start Clim 2005.A1a.

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., et al., 2010. The next generation of scenarios for climate change research and assessment. Nature 463, 747–756. doi:10.1038/nature08823.

Müller, A., 2015. Energy Demand Assessment for Space Conditioning and Domestic Hot Water: A Case Study for the Austrian Building Stock. PhD Thesis. Vienna University of Technology, Vienna.

Müller, A., Biermayr, P., Kranzl, L., Haas, R., Altenburger, F., Weiss, W., et al., 2010. Heizen 2050: Systeme zur Wärmebereitstellung und Raumklimatisierung im österreichischen Gebäudebestand: Technologische Anforderungen bis zum Jahr 2050. Gefördert vom Klima- und Energiefonds.

Munich, RE, 2014. NatCatSERVICE [WWW Document]. Available from: <http://www.munichre.com/de/reinsurance/business/non-life/natcatservice/index.html> (accessed 10.06.14.).

Neunteufel, R., Bock, R., Perfler, R., 2009. ÖVGW Statistikprojekt: Langjährige Datenreihe aus DW1 Daten – Untersuchung möglicher Einflussfaktoren – Endbericht. Österreichische Vereinigung für das Gas- und Wasserfach (ÖVGW), Wien. <www.oevgw.at> (accessed 22.02.16).

Neunteufel, R., Richard, L., Perfler, R., Tuschel, S., Mader, K., Haas, E., 2011. Studie Wasserverbrauch und Wasserbedarf – Teil 1: Literaturstudie zum Wasserverbrauch – Einflussfaktoren, Entwicklung und Prognosen; Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2010, Wien. <http://www.wasseraktiv.at/resources/files/2015/2/23/7104/wasserverbrauch-wasserbedarf-literaturstudie.pdf> (accessed 22.02.16).

Neunteufel, R., Richard, L., Perfler, R., Tuschel, S., Mader, K., Haas, E., 2012a. Wasserverbrauch und Wasserbedarf – Auswertung empirischer Daten zum Wasserverbrauch (Teil 2); Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Wien. <https://www.bmlfuw.gv.at/service/publikationen/wasser.html> (accessed 22.02.16).

Neunteufel, R., Ertl, T., Spindler, A., Lukas, A., Perfler, R., Schwarz, D., et al., 2012b. Technische Herausforderungen in der Siedlungswasserwirtschaft Wien: Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Wien. <https://www.bmlfuw.gv.at/service/publikationen/wasser.html> (accessed 22.02.16).

Neunteufel, R., Friedl, F., Perfler, R., Schrotter, S., Mayr, E., Fuchs-Hanusch, D., 2013. Abschlussbericht zum ÖVGW Benchmarking 2012, Wien/Graz, Februar 2013, Hrsg.: ÖVGW – Österreichische Vereinigung für das Gas- und Wasserfach. <www.trinkwasserbenchmarking.at> (accessed 22.02.16).

Neunteufel, R., Perfler, R., Schwarz, D., Bachner, G., Bednar-Friedl, B., 2015. Water supply and sanitation. In: Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F. (Eds.), Economic Evaluation of Climate Change Impacts. Development of a Cross-Sectoral framework and Results for Austria. Springer, Cham, pp. 215–234.

Nordhaus, W.D., 1991. To slow or not to slow: the economics of the greenhouse effect. J. Econom. 101 (407), 920–937.

Nordhaus, W.D., 2011. Estimates of the social cost of carbon: background and results from the RICE-2011 model. National Bureau of Economic Research Working Paper 17540.

OECD, 2015. The economic consequences of climate change. OECD Publishing, Paris. <http://dx.doi.org/10.1787/9789254235410-enl>.

O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., et al., 2014. A new scenario framework for climate change research: the concept of shared socioeconomic pathways. Clim. Change 122 (3), 387–400.

Pindyck, R.S., 2013. Climate change policy: what do the models tell us? J. Econ. Lit. 51 (3), 860–872.

Prettenthaler, F., Albrecher, H., 2009. Hochwasser und dessen Versicherung in Österreich. Verlag der Österreichischen Akademie der Wissenschaften, Wien.

Prettenthaler, F., Kortschak, D., Hochrainer-Stigler, S., Mechler, R., Urban, H., Steininger, K., 2015. Catastrophe management: riverine flooding. In: Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F. (Eds.), Economic Evaluation of Climate Change Impacts. Development of a Cross-Sectoral framework and Results for Austria. Springer, Cham, pp. 349–366.

Prettenthaler, F., Köberl, J., Bird, D.N., 2016. 'Weather Value at Risk': a uniform approach to describe and compare sectoral income risks from climate change. Sci. Total Environ. 543 (B), 1010–1018.

Rojas, R., Feyen, L., Watkiss, P., 2013. Climate change and river floods in the European Union: socioeconomic consequences and the costs and benefits of adaptation. Glob. Environ. Change 23 (6), 1737–1751. doi:10.1016/j.gloenvcha.2013.08.006.

Schmid, E., 2004). The Positive Agricultural Sector Model Austria – PASMA. University of Agriculture and Life Sciences, Vienna.

Schöner, W., Dos Santos Cardoso, E.M., 2004. Datenbereitstellung, Entwicklung von Regionalisierungstools und einer Schnittstelle zu den regionalen Klimamodellen. ZAMG Report for project year 1 PJ1. In: Reclip:more – Research for Climate Protection: Model Run Evaluation, 1. Jahresbericht, ARC Systems Research. Seibersdorf, Austria.

Schörghuber, S., Seidl, R., Rammer, W., Kindermann, G., Lexer, M.J., 2010. KlimAdapt – Ableitung von prioritären Maßnahmen zur Adaption des Energiesystems an den Klimawandel – Arbeitspaket 3: Biomasse Bereitstellung. Technical Report, University of Agriculture and Life Sciences, Vienna.

Seidl, R., Schelhaas, M.J., Lindner, M., Lexer, M., 2009. Modelling bark beetle disturbances in a large scale forest scenario model to assess climate change impacts and evaluate adaptive management strategies. Reg. Environ. Change 9 (2), 101–119.

Seidl, R., Schelhaas, M.J., Lexer, M.J., 2011. Unraveling the drivers of intensifying forest disturbance regimes in Europe. Glob. Change Biol. 17 (9), 2842–2852.

Steininger, K.W., Koenig, M., Bednar-Friedl, B., Kranzl, L., Loibl, W., Prettenthaler, F. (Eds.), 2015a. Economic Evaluation of Climate Change Impacts. Development of a Cross-Sectoral framework and Results for Austria. Springer, Cham, 468 pp.

Steininger, K.W., Wagner, G., Watkiss, P., König, M., 2015b. Climate change impacts at the national level: known trends, unknown tails, and unknowables. In: Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F. (Eds.), Economic Evaluation of Climate Change Impacts. Development of a Cross-Sectoral framework and Results for Austria. Springer, Cham, pp. 75–99.

Steininger, K.W., Haas, W., König, M., Pech, M., Prettenthaler, F., Prutsch, A., et al., 2015c. Die Folgeschäden des Klimawandels in Österreich. Dimensionen unserer Zukunft in zehn Bildern für Österreich, ACRP in essence. Austrian Climate Research Programme, Klimafonds, Vienna.

Stern, N., 2007. The Economics of Climate Change: The Stern Review. Cambridge University Press, Cambridge and New York.

Tol, R., 2002a. Estimates of the damage costs of climate change, Part I: benchmark estimates. Environ. Res. Econ. 21 (1), 47–73.

Tol, R., 2002b. Estimates of the damage costs of climate change, Part II: dynamic estimates. Environ. Res. Econ. 21 (2), 135–160.

Totschnig, G., Kann, A., Truhetz, H., Pfleger, M., Ottendörfer, W., Schauer, G., 2013. AutRES100 –Hochauflösende Modellierung des Stromsystems bei hohem erneuerbaren Anteil – Richtung 100% Erneuerbare in Österreich. Endbericht im Rahmen des Programms Neue Energie 2020, Wien. <http://eeg.tuwien.ac.at/AutRES100/Endbericht.pdfl> (accessed 09.02.16).

Totschnig, G., Müller, A., Hummel, M., Hirner, R., Nachtnebel, H.P., Stanzel, P., et al., 2014. Climate change impact on the electricity sector: the example of Austria and Germany. PRESENCE Working Paper, Energy Economics Group, Vienna University of Technology. <http://www.eeg.tuwien.ac.at/eeg.tuwien.ac.at_pages/research/downloads/PR_356_08_PRESENCE_electricity_working_paper.pdfl> (accessed 09.02.16).

Töglhofer, C., Mestel, R., Prettenthaler, F., 2012. Weather value at risk: on the measurement of noncatastrophic weather risk. Weather Clim. Soc. 4, 190–199.

Urban, H., Steininger, K.W., 2015. Manufacturing and trade: labour productivity losses. In: Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F. (Eds.), Economic Evaluation of Climate Change Impacts: Development of a Cross-Sectoral Framework and Results for Austria. Springer, Cham, pp. 301–322.

van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., et al., 2011. The representative concentration pathways: an overview. Clim. Change 109, 5–31.

van Vuuren, D.P., Kriegler, E., O'Neill, B.C., Ebi, K.L., Riahi, K., et al., 2014. A new scenario framework for climate change research: scenario matrix architecture. Clim. Change 122 (3), 373–386.

Watkiss, P., 2011. Aggregate economic measures of climate change damages: explaining the differences and implications. WIREs Clim. Change 2 (3), 356.

Zulka, K.P., Götzl, M., 2015. Ecosystem services: Pest control and pollination. In: Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F. (Eds.), Economic Evaluation of Climate Change Impacts. Development of a Cross-Sectoral Framework and Results for Austria. Springer, Cham, pp. 169–189.